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Removal of the precursors of regulated DBPs and TOX from surface waters and wastewater effluents using mixed anion exchange resins

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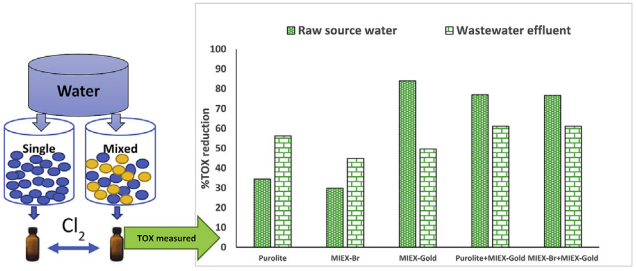
HIGHLIGHTS

- Mixed and single anion exchange resins were tested for the removal of organic and inorganic DBPs precursors from water.
- Formation of total organic halides (TOX) was more reduced from wastewater effluents treated by the mixed resin system.
- Doubling the resin dose resulted in less than 10–20% improvement in DBP precursors' removal.

GRAPHICAL ABSTRACT



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ABSTRACT

Both organic and inorganic precursors play important roles in the formation and speciation of disinfection by-products (DBPs). This study aimed to investigate the efficacy of three different anion exchange resins for removing both organic and inorganic DBP precursors simultaneously in a single treatment system. Resins in the single (Purolite®-Br, MIEX®-Br, and MIEX®-Gold) and mixed (Purolite®-Br with MIEX®-Gold and MIEX®-Br with MIEX®-Gold) application modes were tested and compared for the removal of dissolved organic carbon (DOC), bromide (Br^-), and iodide (I^-) from a raw source water and a treated wastewater effluent. Uniform formation condition (UFC) tests were conducted to measure the concentrations of trihalomethanes (THM4), haloacetic acids (HAA9), haloacetonitriles (HAN6), and total organic halides (TOX): total organic chlorine (TOCl), total organic bromine (TOBr), and total organic iodine (TOI) before and after the anion exchange resin treatments. The anion exchange treatment substantially lowered the DOC, UV_{254} absorbing matter, dissolved nitrogen (DN), Br^-, and I^-. Consequently, the formation of THM4, HAA9, HAN6, and TOX in the examined chlorinated water samples were reduced significantly. The maximum reduction in THM4 and TOX (66–69% and 61%, respectively) from wastewater effluent was achieved by the mixed resin system, which also reduced the THM4 and TOX by 77% and 77%, respectively, from raw source water. Overall, mixed resin systems (a DOC-selective and a Br-selective resin) resulted in lower amounts of THM4 and HAA9 formation during subsequent chlorination with lower bromine incorporation as compared to single resin systems. Furthermore, they exhibited lower TOBr formation, while TOI formation was not detected.

1. Introduction

Disinfectant use is crucial for maintaining safe drinking water

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quality and preventing waterborne microbial diseases (Richardson et al., 2007). Chlorine is the most widely used oxidant in water disinfection and treatment (Cortés and Marcos, 2018; Deborde and von Gunten, 2008; Ding et al., 2019). One unintended consequence of chlorination, however, is the formation of disinfection by-products (DBPs) as a result of reactions between chlorine and organic [natural organic matter (NOM), algal organic matter (AOM), effluent organic matter (EfOM)] and inorganic [bromide (Br^-) and iodide (I^-)] precursors (Beita-Sandí et al., 2018; Kampioti; Stephanou, 2002; Soyluoglu et al., 2020). These DBPs have been shown to pose adverse impacts on public health (Villanueva et al., 2015), and bromo- and iodo-DBPs exhibit higher toxicity than their chlorinated analogs (Cortés and Marcos, 2018; Liviac et al., 2010; Plewa et al., 2004; Plewa and Wagner, 2019). As a result, some of the DBPs are currently regulated in drinking waters and wastewater effluents around the world (Richardson et al., 2007; U. S. EPA, 2010).

The approaches that are used to control and reduce the formation of DBPs in drinking water include removing organic precursors, using alternative disinfectants or disinfection scenarios, and/or removal of DBPs after formation (Bougeard et al., 2010; Ding et al., 2019; Fang et al., 2010; Karanfil et al., 2008; Soyluoglu et al., 2020). Using alternative disinfectants to reduce regulated DBPs may lead to the production of other types and classes of DBPs with higher toxicity (Liviac et al., 2010; Muellner et al., 2007; Plewa et al., 2004; Richardson et al., 2007), while it is not feasible to remove all DBPs after their formation (Karanfil et al., 2008). Precursor d has been viewed as the most effective approach to reduce the formation of DBPs (Karanfil et al., 2008). To date, the main focus has mainly concentrated on organic precursor removal, with little to no attention given on removing inorganic precursors or removing both organic and inorganic precursors simultaneously.

Conventional water treatment processes (coagulation, flocculation, sedimentation) remove organic precursors from water in the range of 20–60% (Joseph et al., 2012; Mohd Zainudin et al., 2018; Sillanpää et al., 2018), but they are not effective in removing inorganic precursors (Ates et al., 2009; Kristiana et al., 2011; Singer and Bilyk, 2002; Xu et al., 2013; Yang et al., 2019). In waters with elevated bromide levels, this results in an increase in the Br^-/DOC ratio and promotes the formation of brominated DBPs with higher toxicity (Phetrak et al., 2014). Thus, new and advanced treatment technologies are needed to remove inorganic precursors. With the recent advances, selective anion exchange resins can provide viable alternatives (Boyer and Singer, 2005; Hsu and Singer, 2010; Neale and Schäfer, 2009; Walker and Boyer, 2011). Studies have been conducted using a single resin to examine both DOC and bromide removals (Hsu and Singer, 2010). The removal of Br^- and NOM from water using a polyacrylic or polystyrene resin in single and two-stage configuration was investigated, and it was found that MIEX®, a DOC-selective resin, was more effective in DOM removal, while a polystyrene resin performed better in removing Br^-, which was attributed to the Br^- diffusion into the inner pores of the resin (Hsu and Singer, 2010). MIEX® was examined to remove both DOC and Br^- from surface water, and it was found that MIEX® was more effective than coagulation in removing DOC and UVA_{254} absorbing matter, while Br^- removal ranged from 15 to 45% depending on source water background composition (Boyer and Singer, 2005). In another study, coagulation enhancement for the removal of organic matter using MIEX® was shown to reduce THMs and HAAs formation potential by 60–90%, with higher reduction in higher SUVA waters (Singer and Bilyk, 2002; Xu et al., 2016, 2013). MIEX® was also employed to treat surface waters and simulated impacted waters, and the results showed a decrease in the formation potential of THM4 and HAA9 (Gan et al., 2013). MIEX®, when used alone and in combination with powdered activated carbon to treat synthetic wastewater and biologically treated secondary effluent, was able to remove 60% of DOC (mainly the hydrophilic portion) from wastewater (Zhang et al., 2006). Five anion exchange resins (polyacrylic and polystyrene) were used for the removal of Br^- and DOM, followed by investigating THM reduction and speciation in bottle–point experiments, showed that MIEX® significantly reduced chlorinated THMs, whereas polystyrene resins were more effective for brominated THM control (Phetrak et al., 2014). Recently, we compared the performance of anion exchange resins, including two novel Br^- selective resins, for the removal of Br^- (Soyluoglu et al., 2020). The resins' performance was evaluated under both typical and challenging background water conditions by varying the concentrations of anions and organic matter. The results showed that both the subsequent formation of DBPs (THM4, HAA9, and HAN6) and the total organic halogens (TOX) decreased by ~90% under uniform formation conditions.

All previous reviewed studies were conducted by using a single resin application mode. In this study, we hypothesized that the combined use of a DOC-selective and a Br-selective resin in a single treatment tank would allow simultaneous removal of both DOC and Br^- while lowering both total as well as brominated DBP formation as compared to single resin systems. Therefore, we conducted experiments to compare simultaneous removal of organic (NOM and EfOM) and inorganic (Br^- and I^-) DBP precursors from water using mixed (i.e., two resins) with those of single-resin systems in both drinking water and water reuse settings. In addition to regulated DBPs (THM4 and HAA9), unregulated HAN6 formation and TOX speciation were also characterized.

2. Materials and methods

2.1. Water samples

The water samples were obtained from the source of a surface water treatment plant and the effluent of a municipal wastewater treatment plant (Bardenpho Process) prior to disinfection and before any oxidant/disinfectant addition. Upon arrival to the laboratory, they were filtered with 0.2 μm pore size Whatman™ Polycap 150 TC filters and stored at 4 °C until the experiments were conducted within 2–3 days. Before anion exchange treatment, the DOC of the two water samples was adjusted to 5 mg/L by diluting with distilled and deionized water as necessary. Br^- and I^- were adjusted to achieve 250 μg/L and 100 μg/L initial concentrations, respectively. An unusual very high concentration of I^- was used in the experiments to facilitate the measurement of its removal after resin treatments.

2.2. Anion exchange resins and treatments

Purolite® Bromide Plus/9218 was obtained from the Purolite® chemical manufacturing company (PA, USA), while MIEX®-Bromide and MIEX®-Gold resins were obtained from IXOM Watercare (Centennial, CO, USA). The resins and their selected characteristics are presented in Table S1 in the SI.

Before the experiments, the impurities of resin were cleaned as detailed in our previous studies (Beita-Sandí et al., 2018; Gan et al., 2013; Soyluoglu et al., 2020). Ion exchange treatment experiments were conducted using a Phipps & Bird jar tester (Richmond, VA, USA), with a contact time of 15 min at the rate of 150 rpm; more details are in our previous studies (Beita-Sandí and Karanfil, 2017; Soyluoglu et al., 2020). We conducted the experiments at 300 and 600 bed volume (bed volume (BV) = volume of treated water/volume of resin) using 3000 mL water/10 mL resin and 3000 mL water/5 mL resin, respectively. In case of mixed resins, equal amount of each resin was mixed to achieve the required resin

volume.

2.3. DBP and TOX UFC tests

A uniform formation condition (UFC) test to simulate the formation of DBPs under representative distribution conditions in the United States was applied to investigate the formation of DBPs and TOX after treating waters using resins (more information is available in the SI). Prior to chlorination, samples were buffered to maintain the pH of 7.8 ± 0.2 using 10 mM phosphate buffer. A stock chlorine solution (1000 mg/L as Cl_2) was prepared by diluting sodium hypochlorite (Baker Analyzed Reagent, 5% available free chlorine). Samples were dosed with the required chlorine amount from the diluted stock solution to achieve a free chlorine residual of 1 mg/L as Cl_2 after 24 h of reaction time. Analytical methods and their minimum reporting levels (MRLs) for the parameters used in this study are provided in Table S2 in the SI.

3. Results and discussion

3.1. Water characteristics

The selected characteristics of water samples used in this study are summarized in Table 1. The $SUVA_{254}$ values of the diluted raw source water and wastewater effluent samples were 4.2 and 2.2 L/mg-m, respectively. The low $SUVA_{254}$ of the wastewater effluent is consistent with the typical effluent wastewater organic properties that are rich in hydrophilic and non-aromatic organic matter (soluble microbial products) (Gan et al., 2013; Kabsch-Korbutowicz et al., 2008), whereas the raw source water organic matter was rich in aromatic character as it originated from a terrestrial watershed.

Before resin treatment experiments, the DOC values of water samples were diluted to 5 mg/L, and they were spiked with Br^- and I^- to achieve 250 μg/L Br^- and 100 μg/L I^-. The THM4, HAA9, HAN6, and TOX of the raw source water before treatment with resins were 256 μg/L, 204 μg/L, 5 μg/L, and 532 μg/L, respectively, whereas the values for the wastewater effluent were 123 μg/L, 128 μg/L, 11 μg/L, and 375 μg/L, respectively (Figs. 1 and 2). At the same DOC levels, raw source water formed more THM4, HAA9, and TOX than the wastewater effluent, which was attributed to its higher content of UV_{254}-absorbing materials ($SUVA_{254}$ = 4.2 L/mg-m). On the other hand, HAN6 formation was higher in the wastewater effluent due to its higher nitrogenous organic content and to the higher reactivity of the EfOM compared to NOM in forming HANs (Table 1).

3.2. Removal of Br^-, I^-, DOC, UV_{254}, and DN by single and mixed resin treatment

The removals of Br^-, I^-, DOC, UV_{245} absorbing matter, and DN by different resin treatment conditions are shown in Fig. 3. The resins applied at 300 bed volume, either in single (i.e., 10 mL of resin) or mixed (i.e., 5 mL + 5 mL of two resins) systems, removed Br^- more efficiently in raw source water than in wastewater effluent. The maximum Br^- removals were 95% and 78% from raw source water and wastewater effluent, respectively, using Purolite® bromide selective resin. On the other hand, the lowest removal of Br^- was observed by MIEX®-Gold, the DOC-selective resin, in both raw source water (84% removal) and wastewater effluent (31% removal). Mixed resin experiments (Purolite® with MIEX®-Gold) and (MIEX®-Br with MIEX®-Gold) exhibited 91% and ~70% of Br^- removal from raw source water and wastewater effluents, respectively (Fig. 3 A). Almost complete removal of I^- was achieved by Purolite® and MIEX®-Br resins in the single form in both raw source water and wastewater effluents; however, slightly lower I^- removals (less than 10%) were observed for these resins in the mixed resin experiments from raw source water (Fig. 3 B). More iodide removals may be attributed to the difference in ion size and solubility (Singare and Lokhande, 2012).

In terms of DOC, the maximum removal was observed by MIEX®-Gold resin from both raw source water and wastewater effluent (85% and 48%, respectively), while Purolite® and MIEX®-Br removed slightly more DOC from wastewater effluent (Fig. 3 C). The higher DOC removal in the raw source water could be attributed to its higher aromatic content and the removal of UV-absorbing DOC components (Fig. 3 E). The preferential removal of higher SUVA organic matter by MIEX® has also been reported in previous studies (Boyer and Singer, 2005; Gan et al., 2013; Singer and Bilyk, 2002; Xu et al., 2013). Moreover, MIEX®-Gold resin also exhibited higher sulfate selectivity that likely caused less DOC removal from wastewater effluents with higher sulfate levels (Soyluoglu et al., 2020). Mixed resins exceeded DOC removal by Purolite® and MIEX®-Br in the single form in both raw source water and wastewater effluent, but they displayed lower DOC removal as compared to MIEX®-Gold in its single form in the raw source water (Fig. 3 C). Similar UV_{254} reduction trends by single and mixed resins were observed (Fig. 3 E). The highest reduction of UV_{254} was achieved by MIEX®-Gold, with 75% and 65% removal of UV_{254} absorbing material from raw source water and wastewater effluent, respectively. Similar reductions in UV_{254} have been reported in previous studies (Boyer and Singer, 2005; Gan et al., 2013; Singer and Bilyk, 2002; Xu et al., 2013). The mixed resins (Purolite® with MIEX®-Gold) and (MIEX®-Br with MIEX®-Gold) compared to single Purolite® and MIEX®-Br removed more UV_{254} absorbing material due to the presence of DOC-selective MIEX® resin.

The maximum DN removal was achieved by Purolite® and MIEX®-Br in the single form from wastewater effluent and raw source water (~80% and 53%, respectively) (Fig. 3 D). MIEX®-Gold achieved the lowest removal of DN from both wastewater effluent and raw source water (33.9% and 42.8%, respectively). This was attributed to the higher DN levels in wastewater levels and higher selectivity of Purolite® and MIEX®-Br to NO_3^-, while MIEX®-Gold exhibits higher SO_4^{2-} selectivity (Soyluoglu et al., 2020). Both forms of mixed resins were more efficient in removing DN from wastewater effluent (~70%) than raw source water (~50%). Among all treatments (single and mixed resins), MIEX®-Gold achieved the least DN removal from raw source water and wastewater effluent.

Increasing the resin dose from 5 mL (BV 600) to 10 mL (BV 300) at the same contact time (15 min) improved the removal of Br^- and I^- slightly (~10%) in both raw source water and wastewater effluent (Fig. S1 A and B), while increasing DOC removal in the range of 10–20% (Figure S1 C). Similar slight improvements in removal by

Table 1
Characteristics of diluted source water and wastewater effluent used in the experiments.

Sample	DOC (mg/L)	UV_{254} (cm^{-1})	$SUVA_{254}$ (L/mg-m)	DN (mg/L)	Br^- (μg/L)	NO_3^--N (mg/L)	NO_2^- −N (μg/L)	SO_4^{2-} (mg/L)
Raw source water	5	0.21	4.2	0.6	15	0.19	–	2.8
Wastewater effluent	5	0.11	2.2	8.0	45	6.9	70	15

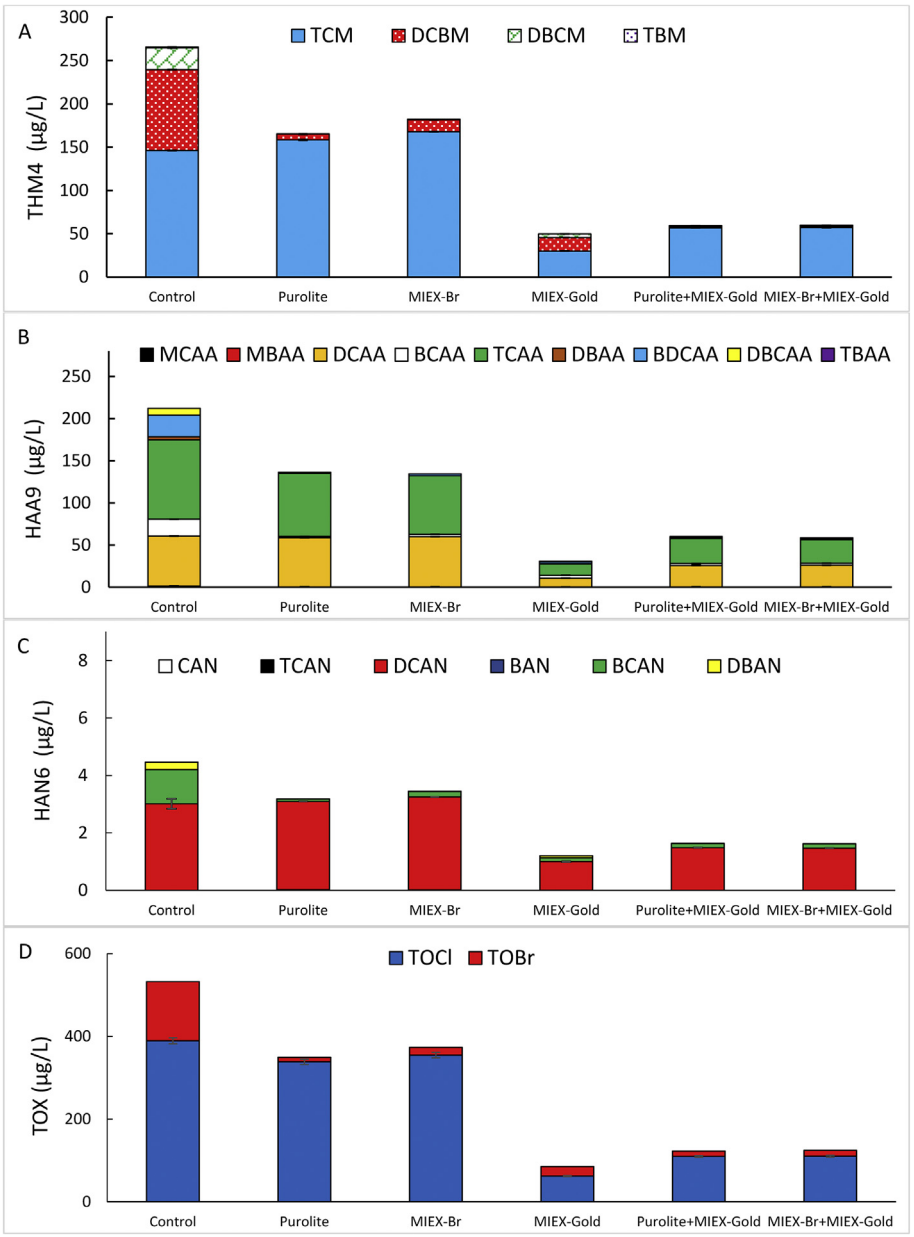

Fig. 1. DBPs [A) THM4, B) HAA9 C) HAN6 and D) TOX] formation from raw source water before (control) and after treatment with single and mixed resins (BV 300), contact time 15 min, settling time 2 min.

increasing the resin dose was observed by Nguyen et al. who reported that increasing resin dose from 5 mL/L to 10 mL/L of MIEX® TMP-TMA resulted in 54% and 64% of DOC removals, respectively, whereas it was 55% and 77% for MIEX®, respectively (Nguyen et al., 2011). Slight improvements in UV_{254} reduction by doubling the resins doses was noticed (Figure S1 D). Better removal improvements were observed for DN and UV_{254} by doubling the resin dose of Purolite and MIEX-Br resins, but slight improvement was achieved by doubling the dose of MIEX-Gold resin (Figure S1 E).

3.3. DBPs and TOX reduction by single and mixed resins

The treated waters from single and mixed resin experiments were chlorinated under uniform formation conditions for trihalomethanes (THM4) [trichloromethane (TCM), dichlorobromomethane (DCBM), dibromochloromethane (DMCM), and tribromomethane (TBM)], haloacetic acids (HAA9) [monochloroacetic acid (MCAA), monobromoacetic acid (MBAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), dibromoacetic acid (DBAA), bromochloroacetic acid (BCAA), bromodichloroacetic acid (BDCAA), chlorodibromoacetic acid (CDBAA), tribromoacetic acid (TBAA)], haloacetonitriles (HAN6) [monochloroacetonitriles (MCAN), dichloroacetonitrile (DCAN), trichloroacetonitrile (TCAN), monobromoacetonitrile (MBAN), dibromoacetonitrile (DBAN), bromochloroacetonitrile (BCAN)], and total organic halides (TOX) [total organic chlorine (TOCl), total organic bromine (TOBr), and total organic iodine (TOI) analyses to evaluate the DBPs precursors' removal efficiency by different resin treatments.

In the raw source water, THM4 formation decreased after single resin treatments, with a maximum decrease of 81% after the MIEX®-Gold resin treatment (Fig. S2 in the SI). This was attributed to the high removal of DOC and some Br^-, mainly the aromatic

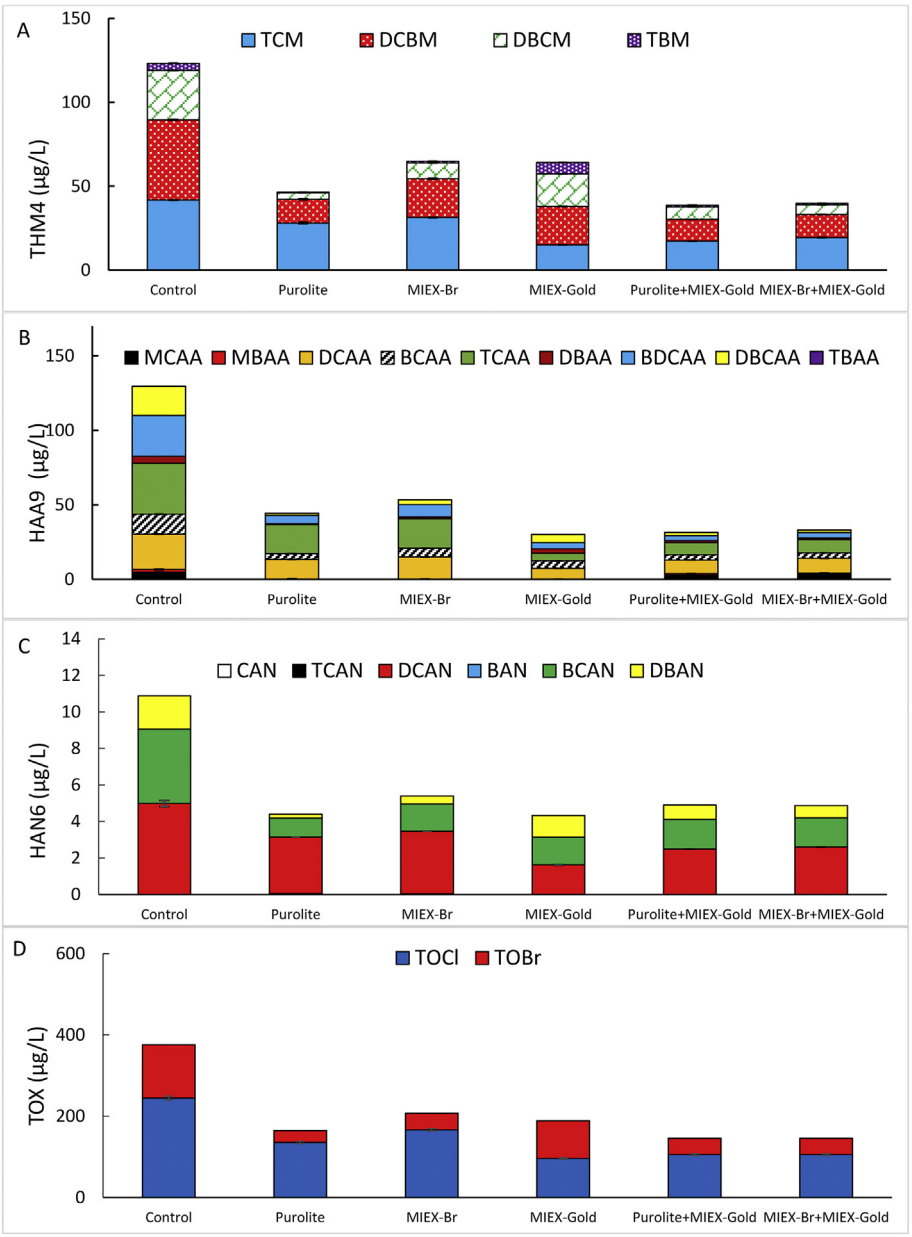

Fig. 2. DBPs [A) THM4, B) HAA9 C) HAN6 and D) TOX] formation from wastewater effluent before (control) and after treatment with single and mixed resins (BV 300), contact time 15 min, settling time 2 min.

(high SUVA) DOC portion that contributed more toward the formation of THMs. Purolite® and MIEX®-Br resins alone decreased THM4 by 37% and 31%, respectively. While the formation of brominated THMs were reduced, TCM formation was slightly increased after treatment of raw source water with Purolite® and MIEX®-Br due to the increasing DOC/Br^- ratio. Treatment with mixed resins (Purolite® with MIEX®-Gold; MIEX®-Br with MIEX®-Gold) resulted in a 77% reduction of THM4, and almost no brominated THM species were detected (Fig. 1 A). Treatment with mixed resins (Purolite® with MIEX®-Gold; MIEX ®-Br with MIEX®-Gold) reduced THM4 more than either Purolite® or MIEX®-Br in the single form. In the wastewater effluent sample, the use of mixed resins (Purolite® with MIEX®-Gold; MIEX®-Br with MIEX®-Gold) achieved maximum reduction in THM4 formation (69% and 66%, respectively) (Fig. S2 in the SI). Furthermore, the best reduction in brominated THM formation was observed with mixed resin systems.

Bromine substitution factor (BSF) is used as a measure of bromine substitution among different DBP classes (Hua and Reckhow, 2012). BSF is the ratio of the molar concentration of bromine in a given DBP class to the total molar concentration of chlorine and bromine in that DBP class (varying from 0 to 1). Table 2 shows the calculated BSF for DBPs formed from raw source water and wastewater effluent before and after treatment with resins in the single and mixed forms. Raw source water's BSF value for all DBP classes is lower than that of wastewater effluent, which can be explained by the difference in organic matter characteristics (i.e., $SUVA_{254}$). Generally, the BSF decreased after resin treatment in both water types; however, the decrease was higher in the treated raw source water due to higher Br^- removal (Fig. S3 in the SI). The BSF increase in some cases after treatment with MIEX®-Gold in the single form is attributed to the higher DOC removal and lower Br^-

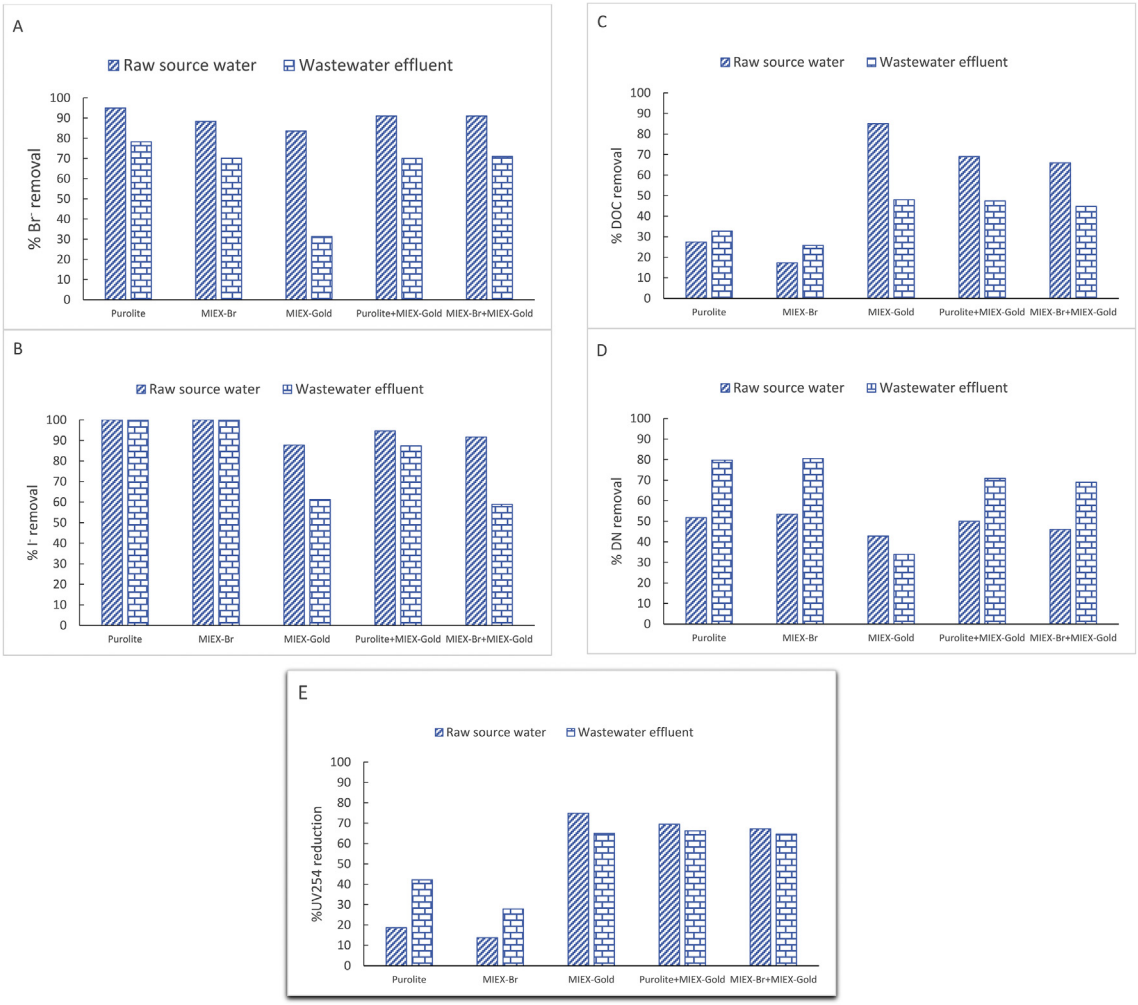

Fig. 3. Removals of Br^- [A], I^- [B], DOC [C], DN [D], and UV_{254} [E] by single and mixed resins (BV = 300), contact time 15 min, settling time 2 min.

Table 2
Bromine substitution factor (BSF) before and after treatment with resins in different settings.

	Water sources	Control	Purolite®	MIEX®-Br	MIEX®-Gold	Purolite® with MIEX®-Gold	MIEX®-Br with MIEX®-Gold
THM-BSF	Raw source water	0.14	0.01	0.02	0.12	0.04	0.04
	Wastewater effluent	0.24	0.12	0.17	0.30	0.19	0.18
HAA-BSF	Raw source water	0.10	0.01	0.01	0.08	0.03	0.03
	Wastewater effluent	0.22	0.09	0.13	0.28	0.16	0.14
HAN-BSF	Raw source water	0.09	0.01	0.01	0.03	0.02	0.03
	Wastewater effluent	0.15	0.08	0.09	0.17	0.13	0.12

removal, which results in an increase in the Br^-/DOC ratio that promotes the formation of brominated DBPs (Phetrak et al., 2014).

The resin treatments reduced substantially the amounts of formed HAA9 in all waters. The maximum decrease (86%) was obtained from MIEX®-Gold resin treatment of raw source water (Fig. S2 B in the SI). Significantly, brominated species of HAAs were effectively decreased and almost approached zero in single and mixed resin treatments. This was attributed to the efficient combined removal of Br^- and DOC. Reduction in HAA9 formation from wastewater effluents was higher with the mixed resin treatment. The mixed resin systems (Purolite® with MIEX®-Gold), (MIEX®-Br with MIEX®-Gold) reduced HAA9 by 77% and 74%, respectively (Fig. S2 B in the SI). Mainly, the formation of DCAA, TCAA, and DBCAA was reduced significantly and to the same extent by the two mixed forms of the resins (Purolite® with MIEX®-Gold; MIEX ®-Br with MIEX®-Gold).

HAN6 formed from the raw source water was reduced by ~50% after MIEX®-Gold and the mixed resin (Purolite® with MIEX®-Gold; MIEX®-Br with MIEX®-Gold) treatment (Fig. 1 C). **Resin treatment reduced brominated HAN formation below the detection** limit as a result of the efficiency of resins in removing DOC and Br^- simultaneously. HAN6, which are usually formed more from wastewater effluents, were reduced almost by ~50% in all single and mixed treatments of resins (Fig. 2 C), with a considerable decrease BCAN compared to DCAN.

The formation of TOX (TOCl and TOBr) before and after resin treatments for both raw source water and wastewater effluent are shown in Fig. 1 D and 2 D, respectively. Mixed resin treatment

resulted in the lowest TOX levels for the wastewater effluent sample. Purolite® and mixed resin treatment resulted in the lowest TOBr levels in both raw source water and wastewater effluent (Fig. 1 D and 2 D). After treating the raw source water with resins, maximum TOCl reduction was achieved by MIEX®-Gold (84%) (Figure S4 B). The mixed resins (Purolite® with MIEX®-Gold; MIEX ®-Br with MIEX®-Gold) reduced TOCl formation from the raw source water by 77%. The higher removal of TOX by MIEX®-Gold can be explained by its being a DOC-specific resin, and in the single resin experiment the resin dose was twice that in the mixed resin experiments, thus removing additional DOC from the raw source water. On the other hand, the two mixed resin systems exhibited higher TOBr removal of ~90% from raw source water (Figure S4 C). The maximum reduction in TOCl formation (61%) from wastewater effluent was observed after treatment with the mixed resin systems (Purolite® with MIEX®-Gold; MIEX ®-Br with MIEX®-Gold). Lower TOX reduction was observed in wastewater effluent compared to raw source water due to the presence of anions such as sulfate and others that compete for the DOC and Br^- removal by resins.

4. Conclusions

The results supported the hypothesis of the study in the tested raw source water and wastewater effluent. In general, mixed resin systems (a DOC-selective and a Br-selective resin) resulted in the formation of lower amounts of THM4, HAA9, and TOBr during subsequent chlorination with lower bromine incorporation as compared to single resin systems. Increasing the resin dose resulted in less than 10–20% improvement in DBP precursors' removal. These findings demonstrate that mixed resin systems present a viable alternative for removal of both organic and inorganic precursors in a single treatment, subsequently producing effluent water with lower concentrations of Br-DBPs, which have been shown to be significantly more cyto- and genotoxic than their chlorinated analogs. Using the anion exchange process in the mixed form is an attractive method for removing DOC and Br^- simultaneously in a single treatment and can be easily combined with conventional flocculation/coagulation processes and membrane filtration processes in water treatment.

Author credit statement

Kanan: contributed to methodology development, conducting the experiments and writing and revision of the manuscript, and Soyluoglu: contributed to methodology development, conducting the experiments and writing and revision of the manuscript, Karanfil: was responsible for the conceptualization, Supervision and administration of the study including writing and revision of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chemosphere.2020.128094.

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